MEMORANDUM

To: Tom Coston
Bitter Root RC&D Area, Inc.
From: John Hinckley, Q.E.P.
Subject: 2008 Stack Test Review
Date: 5 May 2008

INTRODUCTION

At your request, Resource Systems Group has reviewed five stack test reports. All of the stack tests were performed from October, 2007 through March, 2008. Four of the reports correspond to wood chip boilers and one report corresponds to a wood pellet boiler. The stack tests were all conducted by Bison Engineering, Inc. of Helena, Montana. The wood chip boilers are located in Bismarck, North Dakota; Darby, Montana; Victor, Montana, and Dillon, Montana. The pellet boiler is located in Townsend, Montana. Table 1 provides an overview of the boilers.

Table 1: Boiler Summary Information

Location	Bismarck, ND	Darby, MT	Victor, MT	Dillon, MT	Townsend, MT
Combustion Chamber Type	Stoker	Stoker	Stoker	Close-coupled gasifier	Stoker
Heat Input (MMBtu/hr)	1.0	3.3	2.6	19.0	0.75
Facility Served by Boiler	Landfill Buildings	Secondary School Buildings	Secondary School Buildings	University Campus	Secondary School Buildings
Fuel Type	Municipal Vegetation and Pallets	Bole Tree Chips	Bole Tree Chips	Bark	Wood Pellets
Fuel Used during Stack Test	Variable	Lodgepole Pine	Lodgepole Pine	Douglas Fir Bark	Sawdust
Pollution Control Present?	No	No	No	Yes - multicyclone	No

Emissions were tested during "low fire" (low operating capacity) and "high fire" (high operating capacity) according to EPA reference methods. Three one hour tests were performed at low and high fire for each pollutant measured.[1] The following pollutants were measured:

1) Filterable and condensable particulate matter less than or equal to 2.5 microns in aerodynamic diameter (PM2.5),
2) Nitrogen dioxide (NO_2) and
3) Carbon monoxide (CO).

In addition to these pollutants, the following particle size distribution was developed:

1) Percent of total particulate matter (TPM) which is filterable PM2.5,
2) Percent of TPM which is condensable and
3) Percent of filterable TPM greater than 2.5 microns in size.

For the purposes of this memorandum, TPM should be considered the sum of all filterable (solid) and condensable (liquid) particles measured. Filterable and condensable particulate matter are often referred to as the "front half" and "back half" respectively. Filterable PM2.5 is the portion of PM2.5 which can be collected on a filter and is therefore a solid. Condensable particulate matter is the fraction of TPM formed by condensing gases and is therefore a liquid. All condensable matter was assumed to be PM2.5.

The following were reviewed to evaluate boiler performance in addition to reviewing air pollutant emission rates and particle size distributions for each boiler:

1) Air pollutant emissions relative to EPA AP 42 factors.[2].
2) Air pollutant emissions relative to emissions previously measured at Darby, Montana and Thompson Falls, Montana and Council, Idaho.
3) TPM emissions relative to Montana and North Dakota and other state particulate matter emission limits.
4) Boiler combustion efficiency.

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[1] One of the low fire PM2.5 tests at Dillon was voided due to filter plugging.

[2] U.S. Environmental Protection Agency. "Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources." Chapter 1.6, External Combustion Sources. Revised 9/03.

FUEL COMPOSITION

Fuel composition can have a significant affect on emission rates. Table 2 summarizes the fuel properties for the fuel burned at each location. The following become apparent when reviewing this table:

1) Bismarck has the highest fuel heat content. This may be due to the heat content of pallets, which is relatively high given pallets' relatively low moisture content.
2) The Darby, Victor, Dillon and Townsend heat & moisture contents are typical for their respective boiler types.
3) Bismarck has the highest ash content. This is likely due to the fuel processing method at Bismarck. In this, woody material is processed in a tub grinder. Dirt attached to roots and stumps is not separated prior to grinding. Therefore, it travels to the combustion chamber where it contributes to ash formation.
4) Darby and Victor have the same fuel properties. These two sites rely on the same fuel source and therefore have identical fuel properties.
5) Dillon has higher ash content than Darby, Victor and Townsend. This is because Dillon was burning bark which has higher ash content than bole tree chips.

Table 2: Summary of Fuel Properties for each Site

Fuel Parameter	Bismarck	Darby	Victor	Dillon	Townsend
Heat Content (HHV in btu/lb))	10,997	4,675	4,675	5,985	8,161
Ash Content (%)	30.11	0.03	0.03	1.5	0.52
Fuel Moisture Content (%)	5.0	46.3	46.3	33.1	5.1
Nitrogen Content (%)	0.04	0.33	0.33	0.1	0.07

PARTICLE SIZE DISTRIBUTION

Table 3 shows the percent composition of filterable PM greater than 2.5 microns, filterable PM less than and equal to 2.5 microns, and condensable particulate matter (CPM).

Table 3: Summary of Particulate Composition Data

Size Fraction	Operating Capacity	Bismarck	Darby	Victor	Dillon	Townsend
PM > 2.5	Low Fire	17%	48%	30%	8%	56%
	High Fire	33%	36%	48%	22%	56%
	Average	*25%*	*42%*	*39%*	*15%*	*56%*
Filterable PM2.5	Low Fire	46%	45%	61%	79%	31%
	High Fire	26%	54%	49%	75%	34%
	Average	*36%*	*50%*	*55%*	*77%*	*33%*
Condensable PM	Low Fire	36%	8%	9%	9%	13%
	High Fire	42%	7%	3%	3%	10%
	Average	*39%*	*8%*	*6%*	*6%*	*12%*

The following become apparent when reviewing this table:

1) Composition varied significantly between Bismarck and the other wood chip boilers. This is likely due to significant differences in fuel type.

2) Bismarck emits approximately two to three times more condensable PM than the other boilers.

3) Townsend emitted the most particulate matter greater than 2.5 microns (56%) and the least amount of filterable PM2.5 (33%).

COMPARISION OF EMISSION FACTORS

The pounds of pollutant emitted per million Btu's of heat input (lb/MMbtu) were compared for each boiler. Table 4 summarizes low fire, high fire and the average emissions of filterable and condensable PM2.5, CPM, TPM, nitrogen oxides (NOx) and carbon monoxide (CO).

Table 4: Summary of PM2.5, CPM, TPM, NOx and CO Emissions from the Five Boilers (in lb/MMBtu)

Pollutant	Operating Capacity	Bismarck	Darby	Victor	Dillon	Townsend
PM2.5	Low Fire	0.168	0.091	0.097	0.2035	0.176
	High Fire	0.133	0.129	0.099	0.173	0.089
	Average	*0.151*	*0.110*	*0.098*	*0.188*	*0.133*
CPM	Low Fire	0.075	0.015	0.012	0.021	0.052
	High Fire	0.078	0.014	0.007	0.008	0.020
	Average	*0.077*	*0.015*	*0.009*	*0.014*	*0.036*
TPM	Low Fire	0.203	0.172	0.139	0.2212	0.402
	High Fire	0.195	0.212	0.192	0.2483	0.207
	Average	*0.199*	*0.192*	*0.166*	*0.235*	*0.305*
NOx	Low Fire	0.291	0.139	0.153	0.208	0.155
	High Fire	0.289	0.113	0.129	0.170	0.152
	Average	*0.290*	*0.126*	*0.141*	*0.189*	*0.154*
CO	Low Fire	0.354	0.309	0.445	0.086	2.750
	High Fire	0.196	0.221	0.202	0.274	1.055
	Average	*0.275*	*0.265*	*0.324*	*0.180*	*1.903*
PM	Low Fire	*0.128*	*0.157*	*0.127*	*0.200*	*0.350*
	High Fire	*0.117*	*0.198*	*0.185*	*0.241*	*0.188*
	Average	*0.122*	*0.178*	*0.156*	*0.220*	*0.269*

The following conclusions were drawn from this table:

1) Bismarck NOx emissions were approximately two times higher than the other boilers.
2) Bismarck emitted approximately two to six times more CPM than the other boilers.

3) Townsend emitted more TPM and CO than the other boilers. The higher CO emissions may be due to relatively higher airflow through the pellet boiler system per million BTU's of heat input. The ratio of actual cubic feet per million BTU's of heat input (ACF/MMBtu) is approximately 2.8 times greater for the pellet boiler than the average of the three wood chip boilers.

COMPARISON WITH AP 42 AIR POLLUTANT EMISSIONS

Table 1.6-1 and 1.6-2 in section 1.6 of the AP 42 provide emission factors for different types of wood fuels.[1] Therefore, the wood boilers evaluated were grouped according to matching AP 42 emission factors.

Table 5 compares average emissions of PM2.5, TPM, NOx and CO from Bismarck, Darby and Victor with AP 42 emission factors corresponding to uncontrolled emissions from burning wet wood with bark.[2] The AP 42 emission factors selected for PM2.5 and TPM represent the sum of filterable and condensable particles. As shown, only the NOx emission rate for Bismarck was higher than the AP 42 emission rate.

Table 5: Average Wood Chip Boiler Emissions Compared with AP 42 Emission Factors (in lb/MMBtu)

Pollutant	Bismarck	Darby	Victor	AP 42
PM2.5	0.151	0.110	0.098	0.450
TPM	0.199	0.192	0.166	0.580
NOx	0.290	0.126	0.141	0.220
CO	0.275	0.265	0.324	0.600

The two main categories of NOx emissions are called "fuel NOx" and "thermal NOx". Fuel NOx is related to fuel nitrogen content. Thermal NOx is related to combustion temperature; therefore, higher temperatures generally produce higher thermal NOx emissions. The Bismarck boiler had the lowest fuel nitrogen content for all the boilers (0.04%); therefore, it is plausible that the higher NOx emissions were due to higher combustion temperatures. However, combustion chamber temperature was not available.

[1] Table 1.6-1, "Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources." AP 42, Fifth Edition, US EPA. Revised September, 2003.

[2] "Average" refers to the average of low fire and high fire emissions.

Table 6 compares average emissions from the Dillon boiler with AP 42 emission factors. The AP 42 emission factors selected correspond to bark combustion emissions controlled with a mechanical collector. As shown, all actual emissions are less than AP 42 emission factors.

Table 6: Average Dillon Emissions Compared with AP 42 Factors (in lb/MMBtu)

Pollutant	Dillon	AP 42
PM2.5	0.188	0.307
TPM	0.235	0.557
NOx	0.189	0.220
CO	0.180	0.600

Table 7 compares average emissions of PM2.5, TPM, NOx and CO from the wood pellet boiler in Townsend with corresponding EPA AP 42 emission factors. In this case, the AP 42 emission factors correspond to uncontrolled emissions from burning dry wood without bark. As shown, the Townsend emissions are lower than AP 42 emissions for all pollutants except CO.

Table 7: Average Pellet Boiler Emissions Compared with AP 42 Emission Factors (in lb/MMBtu)

Pollutant	Townsend	AP 42
PM2.5	0.133	0.327
TPM	0.305	0.417
NOx	0.154	0.490
CO	1.903	0.600

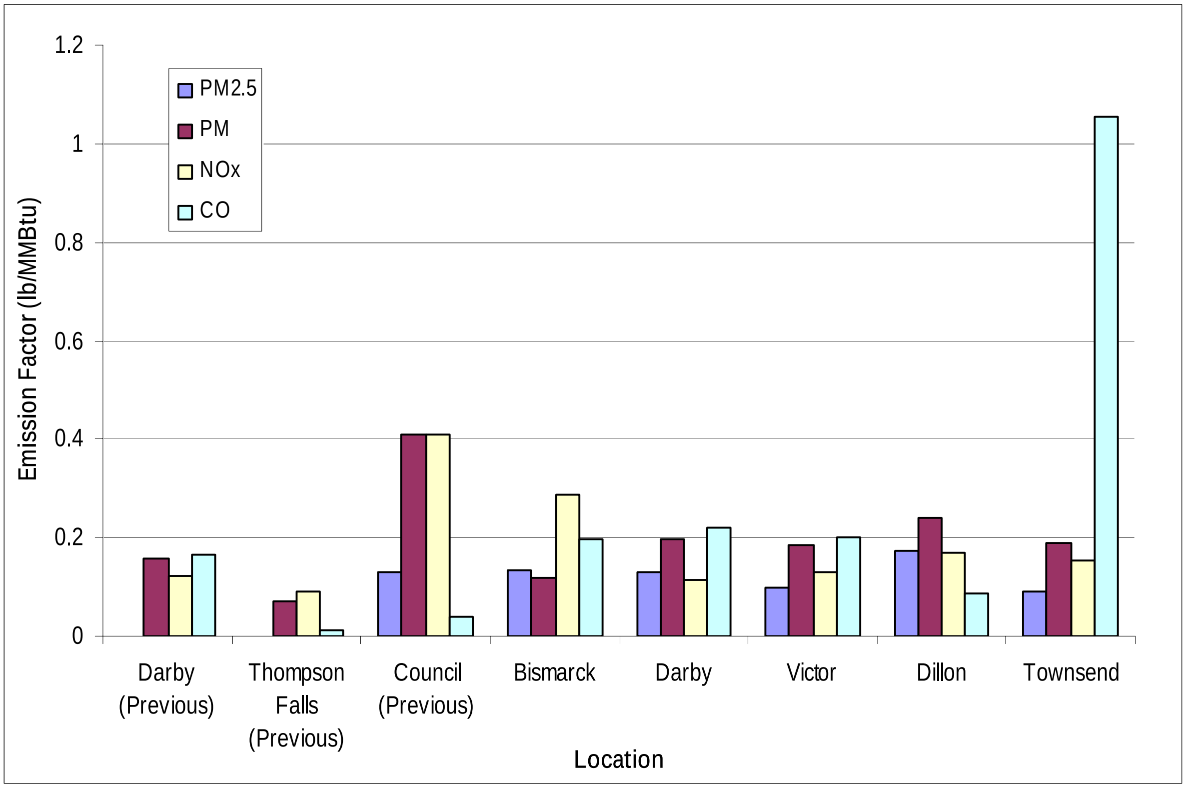
COMPARISION WITH DARBY AND THOMPSON FALLS WOOD-FIRED BOILERS

A comparison of PM2.5, PM, CO and NOx emissions from previous tests at the Council, Darby and Thompson Falls schools' wood boilers is provided in Table 8 and Figure 1 below. CPM was not measured at Darby or Thompson Falls previously; therefore PM (the sum of all filterable particles) was compared. Emissions are compared for high fire operating conditions as that was the operating capacity that was measured at Darby and Thompson Falls previously.

Table 8: Comparison of PM2.5 PM, NOx and CO with Previous Tests (in lb/MMBtu)

	Previous Tests			Recent Tests				
Pollutant	Darby (Previous)	Thompson Falls (Previous)	Council (Previous)	Bismarck	Darby	Victor	Dillon	Townsend
PM2.5	Not avail.	Not avail.	0.129	0.133	0.129	0.099	0.173	0.089
PM	0.156	0.070	0.409	0.117	0.198	0.185	0.241	0.188
NOx	0.122	0.090	0.410	0.289	0.113	0.129	0.170	0.152
CO	0.166	0.010	0.040	0.196	0.221	0.202	0.086	1.055

Figure 1: Comparison of PM2.5, TPM, NOx and CO with Previous Tests (in lb/MMBtu)



The following become apparent when reviewing this information:

1) Council's PM and NOx emissions were relatively high. Recall a relatively unclean fuel was burned at Council. In addition, there were a few operational issues which occurred.
2) Townsend's CO emissions were relatively high. As mentioned, this may be due to the ratio of air to heat input.
3) Thompson Falls' emissions were relatively low.
4) Dillon's PM2.5 emissions were relatively high. This is likely due to the fuel source (bark) which is thought to produce more PM2.5 emissions than other fuel sources.

COMPARISON WITH MONTANA AND NORTH DAKOTA PM EMISSION LIMITS

The boiler at Dillon is the only boiler requiring an air pollution control permit. Consequently, state emission limits do not technically apply to the other boilers. However, it is still useful to compare measured emissions with state emission limits. The emission limit both for Montana and North Dakota is 0.60 lb/MMBtu. Here are emission limits for a number of New England states to put this limit in context:

- Vermont: 0.25 lb/MMBtu (filterable particulate matter only)
- New Hampshire: 0.30 lb/MMBtu,
- Massachusetts: 0.10 lb/MMBtu for critical areas ,
- Massachusetts: 0.20 lb/MMBtu for non-critical areas and
- Rhode Island: 0.20 lb/MMBtu.

These emission limits are not typically attainable without a pollution control device and clean fuel (no dirt, rocks, etc.). The Vermont and New Hampshire limits are likely met with a conventional cyclone or multicyclone. The Massachusetts non-critical area limit and the Rhode Island limit are likely met with a high efficiency multicyclone or a core separator. The Massachusetts critical area limit is likely met with a baghouse or core separator.

The Bismarck, Darby and Victor boilers appear to meet all the standards except the one for Massachusetts non-critical areas.

COMBUSTION EFFICIENCY

The Vermont Air Pollution Control Division (APCD) requires wood-fired boilers to meet a combustion efficiency standard of 99% or greater. The combustion efficiency calculated by this equation is therefore an indicator of the completeness of combustion, not the percent of fuel energy converted to hot water.

The equation used in this case for calculating combustion efficiency, is as follows:

Combustion efficiency (%) = $CO_2/(CO_2 + CO)$

Where:

CO_2 = carbon dioxide concentration in the exhaust gas.

CO = carbon monoxide concentration in the exhaust gas.

Table 9 summarizes the CO, CO_2 and combustion efficiency for the wood boilers. As shown at the bottom of the table, all boilers' average combustion efficiency exceeded 99%. The lowest combustion efficiency is at Townsend. This partly explains the high CO and TPM emissions from this pellet boiler.

Table 9: Summary of CO and CO2 Exhaust Concentrations and Combustion Efficiency for the Boilers

Pollutant/Combustion Efficiency	Operating Capacity	Bismarck	Darby	Victor	Dillon	Townsend
CO (ppm)	Low Fire	215	185	205	32	542
	High Fire	138	168	155	174	340
	Average	*177*	*177*	*180*	*103*	*441*
CO2 (ppm)	Low Fire	90,000	90,000	70,000	70,000	50,000
	High Fire	100,000	110,000	110,000	80,000	50,000
	Average	95,000	100,000	90,000	75,000	50,000
Combustion Efficiency	Low Fire	99.8%	99.8%	99.7%	100.0%	98.9%
	High Fire	99.9%	99.8%	99.9%	99.8%	99.3%
	Average	99.8%	99.8%	99.8%	99.9%	99.1%

CONCLUSIONS

1) Fuel characteristics affect the amount and composition of particulate matter emissions.
2) Actual emissions are typically lower than AP 42 emission factors.
3) Resident state emission limits can be met. However, pollution controls would be necessary for some of the boilers to meet other state emission limits.
4) A relatively high combustion efficiency was attained by all boilers.

Please contact me with any questions.